HYDRODYNAMIC AND WATER QUALITY MODEL ARTHUR R. MARSHALL LOXAHATCHEE NATIONAL WILDLIFE REFUGE

Alonso G. Griborio, Post-Doctoral Research Fellow, Center for Louisiana Inland Water Studies (CLIWS), University of Louisiana at Lafayette (ULL), agg2377@louisiana.edu, 337-482 0643; Ehab A. Meselhe, Associate Professor, Director, CLIWS, ULL, Meselhe@louisiana.edu; Shankar Gautam, Research Associate, CLIWS, ULL, sxg1560@louisiana.edu, Jeanne C. Arceneaux, Graduate Student, CLIWS, ULL, jca1666@louisiana.edu, Emad H. Habib, Assistant Professor, CLIWS, ULL, habib@louisiana.edu; and Michael G. Waldon, Senior Hydrologist, DOI Everglades Program Team – USFWS, Boynton Beach, Fl, mike-waldon@fws.org

Abstract

It is well known that changes in water quantity, timing and quality are introducing negative impacts to the Everglades ecosystem. The changes in natural timing of water levels affect wading birds feeding patterns, apple snail reproductive output, and alligator nesting. Similarly, changes in the spatial distribution of water levels alter the distribution of aquatic vegetation and tree islands. Along with the changes in water quantity and timing, the changes in water quality are an important threat to the Everglades ecosystem. High concentrations of nutrients (specifically phosphorus) in runoff from agricultural areas cause proliferation of cattails, and other undesirable species that negatively affect the ecosystem's balance.

The Water Conservation Area 1 (WCA-1) also known as The Arthur R. Marshall Loxahatchee National Wildlife Refuge is a part of the Everglades that is currently suffering the effects of anthropogenic loads of nutrients and other contaminants and changed hydroperiods. It is a priority for WCA-1 to ensure an appropriate water regulation schedule that will produce maximum benefits for flood control, water supply, fish and wildlife, and prevention of salt water intrusion; and also to better understand and minimize the impacts of the excessive nutrients' loading. This paper describe the current development of a hydrodynamic and water quality model for the Loxahatchee Refuge that will provide a quantitative framework for management decisions related to Refuge inflow and outflow quantity, timing, and quality. When fully calibrated and validated, the model will provide information and assist in answering questions on the hydrologic, hydrodynamic, water quality, and ecologic processes occurring under present conditions and management rules; and how these processes would be altered by different structural changes and management scenarios. Water and phosphorus budget analyses are also being carried out as supplement for the detailed hydrodynamic and water quality modeling.

INTRODUCTION AND BACKGROUND

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (hereafter referred to as the Loxahatchee Refuge or simply as the Refuge) is the only remnant of the northern Everglades in Palm Beach County, Florida (USFWS, 2000). The area of the Refuge is approximately 143,238 acres (58,000 ha) and is located seven miles west of the city of Boynton Beach. The Loxahatchee Refuge is part of a large watershed: the Kissimmee-Okeechobee-Everglades system. Historically, the Kissimmee River discharged into Lake Okeechobee, and during wet cycles the lake would overflow its south bank, providing additional flow to the Everglades (Ligth and Dineen, 1994). This water would sheet flow across the Everglades, but now, water flows through canals and structures, and through a series of water storage areas (Water Conservation Areas, WCAs). During this trajectory, the water not used for municipal water supply and irrigation, is discharged to the Everglades National Park (ENP).

The Loxahatchee Refuge was established at Water Conservation Area 1 (WCA-1) in 1951 (USFWS, 2000). It is now isolated from the historic Kissimmee-Okeechobee-Everglades watershed as it is completely enclosed within a levee system and a borrow canal along the interior of the levee. As shown in Figure 1, the Refuge is bordered on the northwest by drained agricultural land, the Everglades Agricultural Area (EAA), and by mainly an urban development at the east. Water Conservation Area-2A is located at the southwest of the Refuge.

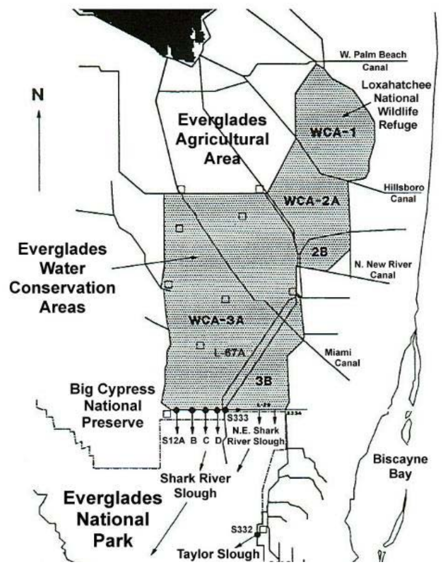

Figure 1 Map of Water Conservation Areas (WCAs).
[Adapted from the Reef Relief Website, http://www.reefrelief.org/Floridabay/report_page4.html]

According to the Comprehensive Conservation Plan for the Refuge (USFWS, 2000) "the construction of the levees has had significant effects on the hydrology, vegetation and wildlife in the refuge." The changes in natural timing of water levels affect wading birds feeding patterns, apple snail reproductive output, and alligator nesting. Similarly, changes in the spatial distribution of water levels alter the distribution of aquatic vegetation and tree islands. In addition, and particularly during the dry season, lower water levels increase the potential for fire and damage to vegetation, soils and wildlife. The U.S. Fish and Wildlife Service (USFWS) in partnership with the South Florida Water Management District (SFWMD) and the U.S. Corps of Engineers are devoting considerable resources to restore and maintain appropriate water regimes for the Refuge.

Along with the changes in water quantity and timing, the changes in water quality are an important threat to the Everglades ecosystem. High concentrations of nutrients (specifically phosphorus) in runoff from agricultural areas cause proliferation of cattails, and other undesirable species that negatively affect the ecosystem's balance. Other negative impacts from increased nutrients include: increased soil phosphorus content, changed periphyton communities, loss of native sawgrass communities, increased organic matter in water, reduced dissolved oxygen, conversion of wet prairie plant communities to cattail, and loss of important habitats for wading birds (Stober et al., 1996).

Along with ensuring an appropriate water regulation schedule, it is a priority for the Refuge to better understand and minimize the impacts of these excessive nutrient loadings. The purpose of the planned Refuge hydrodynamic and water quality modeling is to provide a quantitative framework for management decisions related to Refuge inflow and outflow quantity, timing, and quality. This modeling effort will provide projections of water movement and water quality resulting under alternative scenarios of structure operation, Storm Treatment Area (STA) performance, and structural changes within the Refuge. When fully calibrated and validated, the model will provide information and assist in answering questions on the hydrologic, water quality, and ecologic processes occurring under present conditions and management rules; and how these processes would be altered by different structural changes and management scenarios.

Based on a preliminary inspection of data availability and quality, the period of time from January 1995 to December 2004 was selected as an initial period-of-record (POR) for model calibration and validation. For this POR, the types of data that have been compiled and evaluated are:

- Bathymetric data
- Hydrologic data: stage, inflow and outflow discharges
- Meteorological data: rainfall, temperature, evapotranspiration (ET), and wind
- Water quality data: concentrations of the parameters of interest at available sampling sites.

The initial approach in this modeling effort is to model total phosphorus in the sediments and in the water column. Since velocity measurements are not available in the Refuge, chloride data is being used as tracer to evaluate the model transport subroutine.

SITE DESCRIPTION

Bathymetry

The Refuge bathymetry is characterized by a fairly flat interior marsh elevation and a varying-section rim canal. The latest marsh elevation data for the Refuge are available from the United State Geological Survey (USGS) on a 400 by 400 meter grid. The horizontal and vertical data have an accuracy of +/- 15 cm (Desmond, 2003). Figure 2 shows the bathymetric contours for the Loxahatchee Refuge based on the USGS's data. Results of this survey indicate that, in the Refuge, the bathymetry contours (excluding the rim channel) range from 18.50 to 10.61 ft-NGVD29, with a mean elevation of about 15.17 ft-NGVD29. The Refuge is bordered by the L-7 and L-39 Canals to the west and the L-40 Canal to the east. The rim canal bathymetric data were collected by the University of Florida's Institute of Food and Agricultural Sciences (Daroub et al, 2002). For the western canals, the sediment surface elevations range between 7.0 and -1.5 ft-NGVD29, and between 6.7 and -5.7 ft-NGVD29 for the L-40 Canal. The top width ranges between 120 and 205 ft for the western canals, and between 88 and 173 ft for the L-40 Canal.

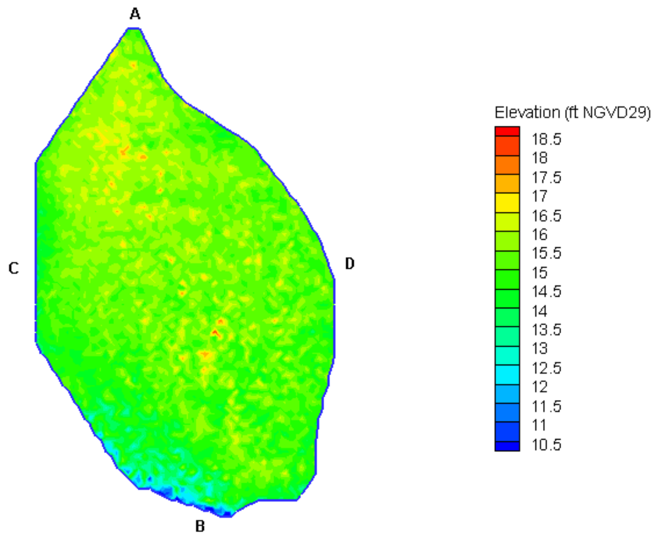

Figure 2 Loxahatchee Refuge 2003 USGS bathymetric data.

Refuge Water Management: Inflows, Outflows, Precipitation and Evapotranspiration

The water entering the Loxahatchee Refuge comes from agricultural and urban runoff, and rainfall, with rainfall constituting approximately 56 to 60 percent of the total input as reported by USFWS (2000) and Richardson et al. (1990). The annual average rainfall for the Refuge is 50.3 inches for the POR, and the maximum daily and monthly values are 7.5 and 18.1 inches, respectively. While the average annual ET estimated for the Refuge is 52 inches.

There are nineteen hydraulic structures associated with the water management of the Refuge. These structures are shown in Figure 3. Runoff enters the refuge through pump stations G-251, and G-310 from Storm Treatment Area-1W (STA-1W), the Acme 1 and Acme 2 (via gate G-94D) pump stations, and historically received discharge from the now-diverted S-6 pump station (diverted to STA-2 in May, 2001) and the S-5A (substantially diverted to STA1-W in August, 1999). At times, significant flows continue to be discharged from the S-5A through bypass gates G-300 and G-301 directly into the Refuge. Bypass of the S-6 discharge directly to the refuge is possible through bypass gate G-338, but such bypasses have not occurred since diversion. Pump station S-362 discharged into the Refuge from STA-1E during the 2004 hurricane season on an emergency basis. The water outlet structures on the Refuge are G-94A, B, and C that provide water supply to the Lake Worth Drainage District (LWDD) on the east side, and the S-10 and S-39 spillways on the south and west side (USFWS, 2000). The S-10 consists of three spillways, i.e, S-10A, S-10C and S-10D (S-10B was proposed but never constructed), and functions as a flood control gate operated by the Corps of Engineers. The S-10E consists of three 6-foot diameter gated culverts, and it is operated as an additional outlet from WCA-1 (see Figure 3) by the SFWMD. The S-39 is operated to make water supply releases from the Refuge during the dry season, and to discharge excess water to the ocean when capacity is available in the Hillsboro Canal and water is not needed in WCA-2 or -3. Water may also be released at the north end of the Refuge through the G-300 and G-301 to the C-51 Canal via the S-5AS for water supply. For the POR, the yearly average inflow to the Refuge is 579,038 acre-ft and the yearly average outflow is 576,141 acre-ft. The annual total outflow is only 0.5% lower than the annual total inflow. The close balance between inflows and outflows through the water control structures, and the fact that the annual average rainfall and potential evapotranspiration (ETp) are also balanced (Abtew et al. 2005), indicates that long-term water losses through seepage may not be significant.

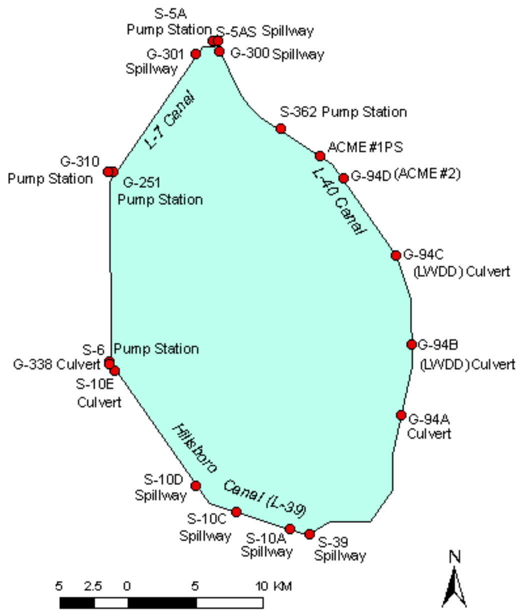

Figure 3 Location of hydraulic structures in the Loxahatchee Refuge.

MODELING EFFORT

<u>Mass Balance Model</u>

Daily, monthly, and annual water budget analyses for the Refuge are conducted for the years of 2002, 2003 and 2004. These years were selected for initial analyses because of the good quality and completeness of the data. The equation used for the Refuge water budget is:

$$V_{in} - V_{out} + P - ET + \Delta S = \varepsilon \qquad (1)$$

where V_{in} is the inflow volume from hydraulic structures, V_{out} is the outflow volume from hydraulic structures, P is precipitation, ET is evapotranspiration, ΔS is the change in storage, and ε is a closure term. For the change in storage, water levels from five interior gages were weight-averaged based on their influence areas. The average stage was used to calculate the Refuge's volume using the software ESRI ArcView 3.2. The stage storage capacity curve for the Refuge is presented in Figure 4.

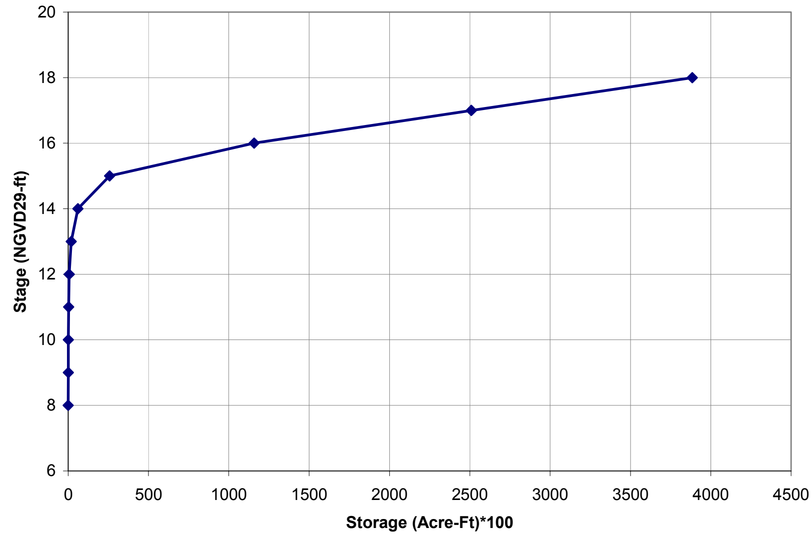

Figure 4 Stage storage capacity curve for the Loxahatchee Refuge.

Table 1 shows the results of the water budget analyses for years 2002, 2003 and 2004. The volumes and the change in storage have been normalized by the Refuge's area and results are presented in inches. In a yearly basis, the results indicate that ε and ΔS are small compared to the other terms in Eq. 1. However, ΔS is comparable to the other terms for the monthly and daily budgets. Therefore, a more accurate stage-storage relationship is being developed for these analyses. Water and phosphorus budget analyses in monthly and daily basis are also under development. The annual budget analysis clearly shows that losses to groundwater are negligible. This conclusion may or may not be applicable to the monthly or daily budgets.

Table 1 Yearly Water Budget Analysis for the Loxahatchee Refuge.

YEAR	VOL IN in	VOL OUT in	PT in	ET in	Δ STORAGE in	ε in
2002	47.846	38.670	45.666	52.106	2.092	0.645
2003	35.910	33.838	48.607	50.342	-1.893	2.230
2004	41.664	39.209	43.080	51.599	-6.073	0.010

Dynamic Models

For this modeling application, the research team evaluated 20 potential candidate models based on a pool of essential and desirable features. After careful consideration the fully dynamic model FVCOM was selected to continue with the hydrodynamic-water quality simulations. FVCOM is an unstructured, finite-volume, three-dimensional model consisting of momentum, continuity, temperature, salinity and density equations closed physically and mathematically using the Mellor and Yamada level 2.5 turbulent closure submodel. The finite-volume method (FVM) used in this model combines the advantages of a finite element method (FEM) for geometric flexibility and a finite-difference method (FDM) for simple discrete computation

(Chen et al., 2004). FVCOM includes a phosphorus-controlled lower trophic level food web model, and WASP-EPA adapted water quality module.

An unstructured triangular mesh was generated for the Loxahatchee Refuge using the MATISSE software. This grid consisted of 33,618 nodes and 63,560 elements. The smaller element sizes are about 10 meters (within and adjacent to the rim canal), and the larger element edges are about 1000 meters (on the central portion of the Refuge). This grid was refined at different locations, allowing for a good representation of the rim canal, and to capture the tree islands. Figure 5 shows a sketch of the unstructured-triangular mesh for the Loxahatchee Refuge.

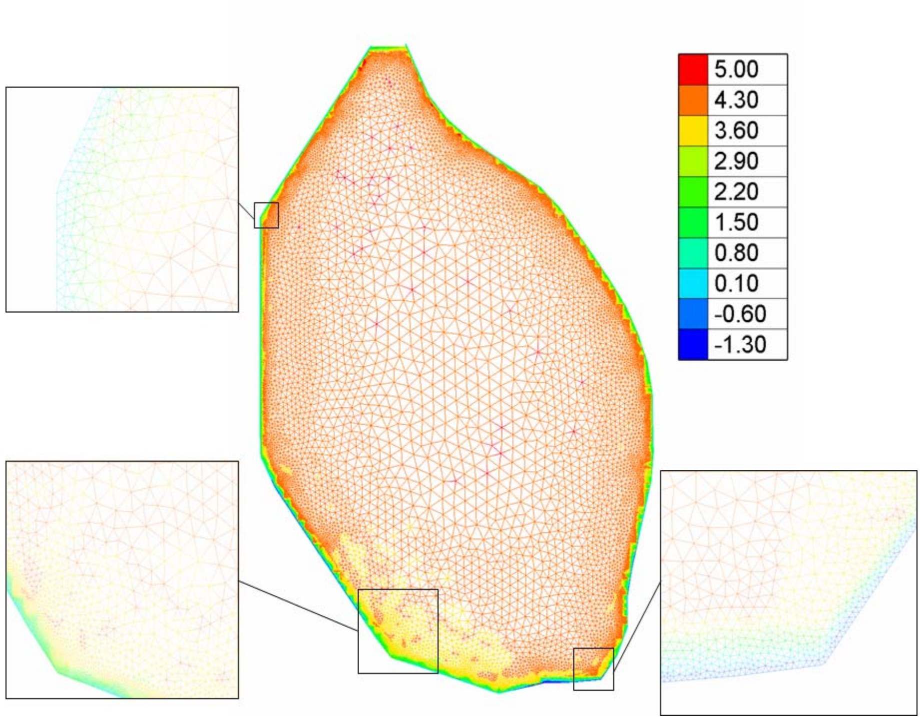

Figure 5 Unstructured grid for the A.R.M. Loxahatchee National Wildlife Refuge.

CLOSING REMARKS

A hydrodynamic and water quality model is currently being set up and calibrated for WCA-1 using the FVCOM model. After completion, this model will provide a quantitative framework for management decisions related to WCA-1 inflow and outflow quantity, timing, and quality. Water and phosphorus mass balance are also being carried out to support the detailed hydrodynamic and water quality modeling.

Annual, monthly, and daily budget analyses are performed to gain a general understanding of the balance of water and phosphorus within the Refuge. The annual analysis shows that the water budget is closed without considering groundwater. Therefore, losses to groundwater may not be significant for the long-term balance. Daily and monthly analyses are under developments and the significance of surface-groundwater interactions will be investigated.

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